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CLOUD ATTENUATION STUDIES

MOUNT WASHINGTON, NEW HAMPSHIRE

By

G. A. Van Lear, Jr.

16.4 Contractor's Report # 71

Division 16 (Optics) Section 4
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University of Michigan
Ann Arbor, Michigan

CONTRACTOR'S REPORT
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N.D.R.C. Contract NDCrc-185
E. F. Barker, Technical Representative
University of Michigan
Ann Arbor, Michigan
October 25, 1945

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National Defense Research Committee

Office of Scientific Research and Development

Division 16 - Section 16.4

Final Report

On

CLOUD ATTENUATION STUDIES

MOUNT WASHINGTON, NEW HAMPSHIRE

(Covering the period from July, 1943 to August, 1944)

By

G. A. Van Lear, Jr.

Submitted by: University of Michigan
Ann Arbor, Michigan

Under Contract No. NDCrc-185

Project Control No. AC - 56

Original Signed By: E. F. Barker
Technical Representative

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Chief, Section 16.4, NDRC

Date: October 25, 1945

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SUMMARY

The objective of the work described in this report was to obtein more raliable quantitative information than hes been previously eveilable on (1) the attenuation coefficient of clouds for visible end near-visible radietion, including a determination of the maximum value likely to be encountered; (2) the correlation between visual range and the ettanuation coefficient. This informetion was desirad specifically in connaction with the NDRC program for developing equipments intended to send and receive such rediation through clouds.

The construction and operation of a Cloud Attenuetion Meter developed for this purpose ere dascribed, and date obteinad during epproximately nine months of operation on the summit of Mount Weshington, New Hampshire, are presented. Theec deta ere restricted to conditions of cloud or fog of high opticel density, for which the visual ranges waro between 50 and 300 feet. No observetions were made on light, fog and haze, with which greetar visual ranges would ba essociated, since data already evaileble for such atmospheric conditions ere reasonably setisfectory, and, moreover, they wera not involvad in the particular epplications under consideration.

Values found for the attenuation coefficient, k, according to the Lambert-Bouguet lew, $I = I_o e^{-kx}$, were

between 1.4 and 5.9 per hundred feet. The validity of this law under the conditions prevailing throughout the experiments was not investigated. A clear-cut, definite correlation, as suggested by Koschmieder's equation, between _k_ values and visual ranga cannot be formulatad from the data. For a given visual range, especially at the higher valuas, there is a considerable spread in tha measured values of _k_. In general, the results for visual ranges between 100 and 150 feet indicate a contrast value intermediate between the values praviously raported by Hulbert and by Houghton on the basis of Koschmieder's law, and for visual ranges betwaen 50 and 100 feet a contrast value even smaller than that established by Hulbert and othars for visual ranges of 10^3 to 10^5 feet, approximately.

Certain difficultias which are inevitably encountered in such measurements, and possible sources of error in these results are briefly discussed.

II. INTRODUCTION

The studies here reported were initiated under Project Control Number AC-56, "Infrared Device for Determining the Position of a Glider With Respect to a Towplane", in connection with the development of devices intended to send and receive a beem of visible or near-visible rediation through clouds. Quantitative information concerning the ettenuation to be expected under e wide variety of conditions wes required. The condition of a cloud with reference to the transmission of radiation is described by the ettenuation coefficient, k, in the expression

$$I = I_o e^{-kx} , \qquad (1)$$

where I_o and I ere the intensities of a parellel beam of radiation before and after treversing the distance x. The velue of k is an index of the optical deneity of a cloud. Following Langmuir and Westendorp[1], we shall elso use the "moan free light path",

$$\lambda_o = 1/k , \qquad (2)$$

the distance in which the intensity fells to the fraction 1/e of its initiel value. It will be convenient to express λ_o in foct, but x in hundreds of feet, and k correspondingly

1 I. Lengmuir and W. F. Westendorp, Physics 1, 273-317 (1931).

per hundred feet. For these units, of course, the factor 100 must be introduced into Eq. (2).

The observation which is most readily made related to optical density is the visual range, or "visibility", i.e., the distance at which a large dark object can be seen on the skyline. Of course, the visual range is determined by the effects of tha scattering medium on visible light, but it is well known that for clean clouds and fogs, as distinct from fine-particle hazes and smokes, the attenuation is substantially non-selective in the neighborhood of the visible spectrum. Visual range observations can, therefore, be used to characteriza clouds and fogs from the near ultra-violet through the near infrared, regardless of the wave-length band under consideration it is necessary to have a correlation between the visual range and the attenuation coefficient, or something equivalent to it.

Middleton[2] discusses at length the theoretical and experimental aspects of the relationship between visual range and attenuation coefficient. He gives the equation due to Koschmieder,

$$x_m = \frac{1}{k} \log_e \frac{1}{\epsilon} = \lambda_0 \log_e \frac{1}{\epsilon} \quad , \tag{3}$$

where $\underline{x_m}$ is the visual range, and ϵ the contrast between the dark object and its surround when it can just be distinguished

[2] W. E. K. Middleton, "Visibility in Meteorology," 2d Ed., University of Toronto Press (1941).

by the eye. The classical value of ϵ is 0.02, and experimental determinations by Hulburt[3] have confirmed the applicability of Eq. (3) with this value at visual ranges between approximately 10^4 and 10^5 feet, with one observation at about 1200 feet in fair agreement. However, Houghton[4] has reported that observations taken in clouds on Mount Washington at visual ranges between 90 and 200 feet called for an ϵ of 0.065, with values of λ_o ranging down to 35 feet (k up to 2.9 per 100 feet).

Since interest for the NDRC applications centered on optical densities equal to, and possibly greater than, those measured by Houghton, and since there appeared to be no theoretical grounda for expecting a different value of ϵ to be applicable under these conditions, it was considered necessary to conduct further investigationa.

In studying the results of correlated observations of optical density and viaual range, it is more convenient to deal with the ratio x_m/λ_o, rather than with the value of ϵ implied through Eq. (3). It is helpful to fix in mind the values of x_m/λ_o corresponding to the valuea of ϵ given above which are as follows:

ϵ	0.02	0.065
x_m/λ_o	3.9	2.7

3 E. O. Hulburt, Journ. Opt. Soc. Am. 31, 467-476 (1941).
4 H. G. Houghton, J. Aer. Sci. 9, 103-107 (1942).

Thus, one object of the work was to study the ratio x_m/λ_o, and to see whether the unexpectedly small value found by Houghton would be continued under conditions comparable to his. If a reliable correlation between x_m and λ_o could be established, simple observations of visual range could be used to predict beam attenuations.

III. RESULTS OBTAINED WITH TEMPORARY SETUP

In connection with other tests being conducted on Mount Washington in July, 1943, a short series of simultaneous observations of visual range and optical density was obtained. The equipment was essentially the cloud attenuation meter to be described in Part IV of this report, but was an earlier model. It was used in the location shown on the map, Fig. 1. The visual range observations were secured by sighting on the southwest roof peak of the Mount Washington Club from points along the railroad track extending generally southwest from the Mount Washington Club.

The results obtained are shown in Table I, which yields 2.65 for the average value of x_m/λ_o, in good agreement with Houghton's determination. It may also be remarked that the spread in values for these observations is comparable with that shown by Houghton's which he kindly allowed the writer to see although they have not been published in detail.

A point of major interest was the maximum optical density to be expected in clouds. The highest value occurring in Table I is 2.9 per 100 feet for k, or 35 feet for λ_o, and this is in line with the results obtained by Houghton. Moreover, Langmuir and Westendorp[1] give 30 feet as their estimate of the shortest mean free path to be expected, which corresponds to 3.3 per 100 feet for **k**. However, none of these results sets a sufficiently conclusive upper limit for **k**.

In order to obtain much more extensive data on the optical densities occurring in clouds, and also to secure further information on the relationship between optical density and visual range, arrangements were made to install a Cloud Attenuation Meter in the Mount Washington Observatory.

IV. THE CLOUD ATTENUATION METER AS INSTALLED IN MOUNT WASHINGTON OBSERVATORY

A. Principles of Operation

As shown in Fig. 2, the Cloud Attenuation Meter consists of a Source-Detector Unit, a Reflector Unit, and a Control-Meter Cabinet. In the Source Detector Unit is a sealed beam flashing signal lamp which sends, along the external path, an unmodulated beam of radiation to the Reflector Unit, located about 60 ft. away. The Reflector Unit is a group of three retrodirective reflectors mounted at the corners of an equilateral triangle as shown in Fig. 6. A motor driven modulating shutter is mounted on an axis passing through the center of this triangle, its three blades successively covering and exposing the three reflectors simultaneously. A second shutter with three blades, mounted on the same axis, may be thrown into either the "open" or the "closed" position by means of electrical controls opereted at the Source. The retrodirective reflectors send much of the rediation, now moduleted, back to the close neighborhood of the source. A perabolic mirror (with euxiliery plane mirror), focuses this rediation on a diffusing gless, behind which is e thelofide photoconductive cell. The output is measured by a meter reading decibels below e reference level determined by an arbitrery verieble sensitivity setting (not celibreted). When the shutter control switch ie shifted from "EXT." to "INT.", the externel peth is effectively closed, and the internal peth opened. The internal peth consists of segments of e Lucite rod speced to permit interruption of the path by a shutter and e moduletor, but which otherwise "conducts" rediation directly from the lamp filament to the diffusing glass, providing e reference signal to which ell readings ere referred in terme of decibel differences. This feeture is considered especielly important, for the internel and external readings are effected identicelly by changes in lamp charecterietics, lemp voltage, photo cell responsivity ("sensitivity"), unmodulated masking flux received either from daylight or by beck-reflection from the beam, and amplifier gein. The necessity for an absolute celibration of the amplifier is thus elimineted. With e thelofide cell es a detector this eutomatic correction for the effect of mesking flux on responsivity is essential. When masking conditions ere changing very repidly, there mey still be some difficulty in obtaining internal and external readings at nearly enough the same time, and it is advantageous to use a thalofide cell which has been selected for minimum dependence of responsivity on masking flux.

In the "noise" position the shutter control switch closes both shutters, and gives a check reading with no signal. Another type of noise reading is obtained with the shutter control switch on "EXT." and the lamp off; this will reveal whether a spurious signal is being registered due to daylight returned by the reflectors.

In using the Cloud Attenuation Meter, it is necessary to obtain "clear" readings in the absence of an appreciable attenuation in order to establish a reference level for the apparatus, from which the attenuation existing when "fog" readings are obtained may be computed. Since the clear reference condition may be separated by hours from the condition of fog or cloud for which the attenuation measurement is desired, the necessity for providing the internal reference signal is apparent. For convenience, the apparatus is so adjusted that the internal reading lies between the clear reading and the usual fog readings.

B. Reduction of Observations

The loss of flux caused by the fog is given in terms of the meter readings by

$$db_F = (db_e - db_i) + (db_i^{\circ} - db_e^{\circ}), \qquad (4)$$

where db_e = external fog reading, db_e^o = external clear reading
db_i = internal fog reading, db_i^o = internal clear reading

Let $\underline{I_o}$ and $\underline{I}$ be the amounts of flux received back at the Source-Detector Unit through clear air and through fog, respectively. Then

$$I/I_o = e^{-2ky} = e^{-2y/\lambda_o} \quad , \qquad (5)$$

where $\underline{y}$ is the distance between the units occupied by fog, and is traversed twice. Since db_F is the decibel measure of this ratio ($\underline{I}$ and $\underline{I_o}$ being treated as voltages in the electrical circuit),

$$db_F = -40 \, (\log_{10} e) \, y/\lambda_o = -17.4 \, y/\lambda_o \qquad (6)$$

Thus

$$= 17.4 \, y/db_F \qquad (7)$$

For the particular installation on Mount Washington, $\underline{y}$ = 58.3 feet, and to good approximation, 17.4 $\underline{y}$ = 1000. Finally, then,

$$\lambda_o = 1000/db_F \qquad (8)$$

C. Construction and Installation

The three units are pictured together in Fig. 3, and interior views are shown in Figs. 4,5 and 6. Figs. 7 and 8 show all the circuits involved. The Source-Detector Unit was installed in the basement of the Mount Washington Observatory, facing the Reflector Unit in the near end of Yankee House. Each unit was placed in a specially-constructed window box which replaced a window sash and projected into the building. Each window box was provided with internal doors, and with external doors which were opened during operation. Thus, there was no glass or other window material between the windows of the units themselves, and they were shielded from precipitation as well as possible. The Control-Meter Cabinet was installed in the instrument room of the Observatory.

Visual ranges were determined on a number of sky-line points at known distances from an observer's station in front of the Observatory. During most of the investigation, one operator took readings of the Cloud Attenuation Meter and recorded also the visual ranges noted by the other observer. Rather late in the investigation, the Observatory staff coupled a General Electric Recording Meter to the decibel meter, and thus obtained continuous recordings of the external reading. This permitted the selection of periods of relatively constant attenuation during the time interval required for a complete set of observations.

V. RESULTS

All observations were taken by the staff of the Mount Washington Observatory, and recorded in an NDRC data book. Carbon copies of these records were mailed periodically to the writer. The results in this report have been obtained from these carbon copies, and from the General Electric Recorder strips transmitted in the same manner. Because of the urgency of other work it was not possible to study the data as they were furnished, or to correspond with the

Observatory staff regarding the conduct of the work.

The general nature of the observations and results is represented in Table II, which contains sample observations chosen to cover substantially the entire region of visual ranges represented. The results are expressed in terms of both k and λ_e, and it is to be noted that optical densities considerably greater than those contemplated during the preliminary tests described in Section III of this report were found. With regard to the values shown for the ratio x_m/λ_e, however, no definite conclusions should be drawn from Table II, since these sample data have been more or less arbitrarily selected from the complete results which will now be discussed.

All the readings of optical density and observed visual range are presented in Table III, except that in the later part of the study, readings at visual ranges greater than 125 feet were ignored. The spread in observed values was so great as to make the labor of correlation not worth while for such data. The correlation has been examined by obtaining for each observation the indicated value of the ratio x_m/λ_e. As has already been remarked, this ratio has been reported as approximately 3.9 for relatively small optical densities and 2.7 for the densities found in clouds. It is at once apparent from Table III that the value of this ratio varies rather widely, and an attempt has been made to study this variation by plotting the ratio against visual range in Fig. 9. Alao shown in Fig. 9 are the earlier data of Table I, the outlying points being connected into an irregular polygon to facilitate examination.

Data taken from the General Electric Recording Meter strips are presented in Table IV, and are represented in Fig. 9 by X's. On account of the large spread which had been found in the manually recorded data, and which seems to be attributable in a considerable degree to unsteadiness in fog conditions, attention was restricted to those portions of the record which indicated steady conditions. It is therefore believed that the X's should be given appreciably more weight than the dots.

The original data include information on meteorological conditions. Almost invariably, the wind velocity was 30-60 miles per hour while observations were being taken. Information on temperature, precipitation, and particle size is enclosed in the original records, but can not here be given in detail.

VI. DISCUSSION

A. Indications from the Data.

From the data plot, Fig. 9, it is apparent that the values obtained for the ratio, x_m/λ_o , hardly give a clear-cut picture. The pattern shows the following characteristics:

1. The experimental values of the ratio for a given visual range scatter considerably--seriously at the greater visual ranges. This is generally

to be expected, since the path of measurement extended somewhat less than 60 feet, and all but the shortest visual ranges had to be observed over a path distinctly different from that for which the instrumental attenuation measurement was made. The smaller values would, therefore, have the greater reliability.

2. The ratio shows an apparent trend toward larger values at the greater visual ranges. This is generally in accord with the indications of earlier work, but occurs at smaller visual ranges, and is of much greater degree, than expected.

3. The values of the ratio are, on the whole, considerably higher than those reported in Section II for the temporary setup (which agreed with Houghton's results), although all three sets of data seem to have been obtained under similar conditions.

4. Whereas it had been intended that the results should enable a choice to be made between the values 0.02 and 0.065 for ϵ, the indications are for an intermediate value for visual ranges between 50 and 100 feet, and for a value less than 0.02 for visual ranges between 100 and 150 feet. The latter indication, in particular, seems hardly plausible.

B. Sources of Error.

The determination of corresponding values of visual range and mean free light path λ_e, or attenuation coefficient k, is unavoidably beset with difficulties which lead to errors. We consider the following sources of error:

1. Differences between path of instrumental measurement and line of visual range observation, both with regard to length and location. When the cloud is non-uniform, and particularly when there is considerable wind (as there almost invariably is on Mount Washington), this is a possible source of serious error, the more so for the greater discrepancies in length. The steadiness or unsteadiness of the readings gives an index of this effect. Shielding by buildings and consistent vertical variation in cloud density would introduce systematic errors.

2. In the Cloud Attenuation Meter itself, non-linearity in response of the thalofide photo-cell could introduce a systematic error. Actually, thalofide cells are known to give non-linear response, but this difficulty was faced in the selection of the cell and the adjustment of the equipment, experimental checks being made with satisfactory results. However, it is possible that the cell characteristics changed with time, or with changes in ambient conditions.

3. Condensation on either or both of the windows covering the Source-Detector Unit and the Reflector Unit would lead to erroneously low values of λ_e, and thus to erroneously high values of the ratio plotted in Fig. 9.

4. It is perhaps possible that some change occurred in the db calibration of the output meter circuit upon which measurements of the db differences between the internal reference level and the external readings, for either clear or cloudy conditions, depend.

VII. CONCLUSIONS

In view of the apparent discrepancies between the earlier and the later data, it does not seem possible to draw any definite conclusion with regard to either the optical densities of clouds found at the summit of Mount Washington, or the correlation between such cloud densities and the observed visual ranges. However, the data tend to support the existence of a trend in this correlation, in the direction to require at the greatest densities a higher contrast between test object and surroundings than the classical value of 0.02.

In order to secure really satisfactory simultaneous data on optical density and visual range, the path of measurement and the line of range observation should be identical.

This requirement is, of course, difficult if not impossible to meet exactly, but in future experimental work every effort should be made to approximate it as closely as possible.

TABLE I

Results Obtained with Temporary Setup

Determinations made 4:21 to 6:03 P.M. July 29, 1943, with Cloud Attenuation Meter as arranged for other tests. Observers were T. W. Hildebrandt and G. A. Van Lear, Jr. First 15 observations, 4:21-4:42 P.M., visual range observations by G. A. Van Lear, Jr. Last 7 observations, 5:52-6:03 P.M., visual range observations by T. W. Hildebrandt.

k, per 100 ft.	Mean Free Light Path, Feet	Observed Visual Range, x_m, Feet	Ratio x_m/λ_e
1.8	56	180	3.2
1.6	62	180	2.9
1.5	67	190	2.8
1.4	72	160	2.2
1.8	56	250	4.5
1.5	67	250	3.8
1.9	53	140	2.7
1.8	56	120	2.2
1.8	56	120	2.2
1.9	53	140	2.7
2.0	50	120	2.4
2.0	50	160	3.2
1.8	56	140	2.5
2.1	48	140	2.9
2.0	50	160	3.2
2.9	35	120	3.5
2.5	40	100	2.5
2.4	42	100	2.4
2.5	40	100	2.5
2.1	47	100	2.1
2.5	40	100	2.5
2.6	38	90	2.3

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TABLE II

Sample Observations and Results, Observatory Installation

Typical observations and results substantially covering the region of visual ranges represented in the observations are shown, without indication of spread in results at each visual range. Roman numerals heading columns correspond to numbers of columns in original data book. The attenuating properties of the cloud (fog) are represented alternatively in terms of the attenuation coefficient **k**, and the mean free light path λ_o. Concerning the apparent trend in the ratio, x_m/λ_o, see Fig. 9, where this ratio is plotted against x_m for more complete data.

----------Cloud Attenuation Meter Determination-----

------Observations-----

Clear $db_i^c - db_e^c$ VII	Fog $db_e - db_i$ VIII	db_F = VII + VIII IX	k, per 100 ft., $= db_F/10$	$\lambda_o = 1000/db_F$ Feet X	Observed Visual Range x_m, Feet XI	Ratio x_m/λ_o
(8.5)	11.1	19.6	1.96	51	230	4.5
(9.0)	20.0	29.0	2.90	34	140	4.1
(10)	31	41	4.1	24	100	4.1
(9.0)	33.2	42.2	4.22	23.7	85	3.6
(10)	36	46	4.6	22	72	3.3
(10.0)	43.4	53.4	5.34	18.8	60	3.2
(10.0)	49	59	5.9	17.0	50	3.0

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TABLE III

Observations and Results, Observatory Installation
Data from Book

Roman numerals heading columns correspond to numbers of columns in original data book. Clear readings in parentheses are those used for reduction of data.

Date	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	db_F= VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m/λ_o
11/8/43	(8.5)	24.0	32.5	130	4.2
		27.4	35.9	127	4.5
		24.5	33.0	145	4.8
	(8.5)	14.0	22.5	270	6.1
		12.0	20.5	280	5.7
		14.0	22.5	210	4.8
11/9/43	(8.5)	3.0	11.5	320	3.7
		10.0	18.5	300	5.6
		12.2	20.7	270	5.6
		14.0	24.5	250	6.1
		11.1	19.6	230	4.5
		20.0	28.5	148	4.2
		25.0	33.5	140	4.7
		33.0	41.5	100	4.2
11/12/43	9.0			infinity	
11/13/43	(9.0)	31.0	40.0	115	4.6
		31.5	40.5	115	4.7
		33.2	42.2	85	3.6
		29.5	38.5	80	3.1
		25.5	34.5	122	4.2
		24.7	33.7	122	4.1
		24.3	33.3	115	3.8
		26.0	35.0	120	4.2
		24.7	33.7	135	4.5
		25.1	34.1	125	4.2
		21.0	30.0	145	4.4
11/14/43	(9.0)	20.0	29.0	140	4.1
		17.7	26.7	145	3.9
		16.0	25.0	160	4.0
		18.3	27.3	140	3.8
		18.0	27.0	145	3.9
		15.9	24.9	148	3.7
		18.7	27.7	148	4.1

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Date	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	$db_T =$ VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m/λ_o
11/15/43	(9.0)	19.5	28.5	135	3.8
11/16/43	9.0			infinity	
11/17/43	9.0			infinity	
	9.3			infinity	
	9.2			infinity	
11/17/43	9.5			in nity	
	9.8			infinity	
11/18/43	(9.5)		35.0	127	4.4
			35.5	127	4.5
			34.5	125	4.3
11/20/43	9.5			infinity	
	10.2			infinity	
	9.7			infinity	
	9.5			infinity	
	9.8			infinity	
	(9.5)	8.5	18.0	145	
11/12/43	(9.5)	49.0	58.5	65	3.8
		46.5	56.0	70	3.9
		47.5	57.0	70	4.0
		39.5	49.0	77	3.8
12/2/43	(9.5)	41.9	51.4	75	3.8
		39.5	49.0	77	3.0
12/3/43	(9.5)	31.0	40.5	125	5.1
		32.8	42.3	80	3.4
12/5/43	(9.5)	7.0	16.5	160	2.6
12/9/43	(9.5)	40.5	50.0	75	3.7
		41.0	50.5	75	3.8
12/9/43	(9.5)	28.9	38.4	77	3.0
12/10/43	(9.5)	10.4	19.9	150	3.0
		9.4	18.9	150	2.8
		7.0	16.5	200	3.3
		16.9	26.4	135	3.6
		13.5	23.0	145	3.3
		14.6	24.1	145	3.5
12/12/43	(9.5)	31.8	41.3	77	3.2
		30.2	39.7	79	3.1

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Date	Clear $db_1^o - db_e^o$ VII	Fog $db_e - db_1$ VIII	db_T = VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m/λ_e
12/15/43	9.2			infinity	
	9.2			infinity	
12/17/43	(9.2)	10.5	19.7	150	3.0
		19.0	28.2	135	3.8
		19.0	28.2	135	3.8
		24.0	33.2	125	4.1
		19.7	28.7	140	4.0
12/18/43	(9.2)	14.3	23.5	160	3.8
		14.7	23.9	140	3.3
		19.6	28.8	145	4.2
		15.0	24.2	140	3.4
		20.0	29.2	130	3.8
12/20/43	(9.2)	30.5	39.7	80	3.2
		21.8	31.0	140	4.3
12/28/43	8.4			infinity	
	8.0			infinity	
1/6/44	(8.4)	15	23.4	145	3.4
		12.1	20.5	165	3.4
1/7/44	(8.4)	-0.8	7.6	310	2.4
1/8/44	8.7			infinity	
	10.8			infinity	
	9.6			infinity	
	9.9			infinity	
	10.0			infinity	
1/10/44	(10.0)	-1.5	8.5	220	1.9
1/10/44	(10.0)	13.7	23.7	160	3.8
		21.5	31.5	145	4.6
		15.9	25.9	145	3.8
1/12/44	(10.0)	21.8	31.8	135	4.3
		17.2	27.2	145	3.9
		9.9	19.9	190	3.8
		12.1	22.1	160	3.5
1/12/44	(10.0)	21.8	31.8	190	6.0
		9.1	19.1	220	4.2
1/13/44	(10.0)	1.7	11.7	250	2.9
		3.0	13.0	240	3.1

Date	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	db_F= VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m/λ_o
1/14/44	(10.0)	29.9	39.9	110	4.4
		30.1	40.1	100	4.0
		30.9	40.9	105	4.3
		29.1	39.1	110	4.3
		36.0	46.0	75	3.4
1/14/44	(10.0)	35.3	45.3	90	4.1
		35.6	45.6	100	4.6
		39.0	49.0	75	3.7
		32.2	42.2	90	3.8
		37.1	47.1	75	3.5
		43.4	53.4	60	3.2
		44.0	54.0	50	2.7
		44.3	54.3	55	3.0
1/15/44	(10.0)	4.5	14.5	230	3.3
		10.7	20.7	170	3.5
		11.0	21.0	150	3.1
1/16/44	10.5			infinity	
	10.4			infinity	
1/20/44	(10.0)	30.3	40.3	120	4.8
		29.9	39.9	125	5.0
		31.8	41.8	110	4.6

Observations at $x_m > 125$ feet are omitted from the rest of this Table

1/26/44	(10)	26	36	125	4.5
		25	35	125	4.4
		25	35	110	3.8
		37	47	100	4.7
		29.4	39	125	4.9
1/27/44	(10)	31	41	85	3.5
		37	47	75	3.5
		30	40	75	3.0
1/29/44	(10)	28	38	100	3.8
		25	35	125	4.4
		22	32	120	3.8
		26	36	95	3.4
		25	35	95	3.3
		25	35	125	4.4
		24	34	95	3.2

Date	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	db_T = VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m/λ_o
2/24/44	(10)	31	41	77	3.2
		31	41	75	3.1
3/15/44	9.9			infinity	
	9.9			infinity	
	9.9			infinity	
3/16/44	(10)	27	37	125	4.6
		23	33	110	3.6
		27	37	125	4.6
		24	34	125	4.3
		26	36	95	3.4
		24	34	75	2.6
3/16/44	(10)	23	33	105	3.5
		24	34	85	2.9
		28	38	100	3.8
		27	37	95	3.5
		25	35	95	3.3
		26	36	90	3.2
		26	36	110	4.0
		26	36	85	3.1
		23	33	95	3.1
3/16/44	(10)	27	37	80	3.0
		27	37	95	3.5
		28	38	80	3.0
		25	35	80	2.8
		26	36	100	3.6
		24	34	80	2.7
3/17/44	(10)	38	48	78	3.7
		41	51	75	3.8
		40	50	75	3.7
		39	49	73	3.6
		34	44	70	3.1
		30	40	88	3.5
	(10)	40	50	75	3.7
		39	49	73	3.6
		30	40	90	3.6
		36	46	77	3.5
		33	43	80	3.4
		29	39	85	3.3
		31	41	84	3.4
3/19/44	9.7			infinity	
	9.6			infinity	
	9.9			infinity	
	10.0			infinity	

Date	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	db_T = VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m / λ_o
3/24/44	(10)	33	43	78	3.4
		36	46	72	3.3
		33	43	70	3.0
		36	46	72	3.3
		34	44	72	3.2
		31	41	80	3.3
		36	46	70	3.2
	(10)	31	41	85	3.5
		31	41	100	4.1
		31	41	80	3.3
		38	48	74	3.5
		39	49	72	3.5
		37	47	71	3.4
		33	43	77	3.3
		38	48	71	3.4
		33	43	82	3.5
4/8/44	(10)	21	31	125	3.9
		24	34	120	4.1
		23	33	120	3.9
		23	33	120	4.0
		21	31	122	3.8
		25	35	100	3.5
		20	30	125	3.7
	(10)	42	52	70	3.6
		42	52	70	3.6
		42	52	73	3.8
		42	52	70	3.6
		43	53	67	3.5
5/8/44	(10)	25	35	80	2.8
		22	32	100	3.2
		18	28	100	2.8
		21	31	115	3.6
6/14/44	8.9			infinity	
	10.4			infinity	
	10.8			infinity	
	10.0			infinity	
6/17/44		24.2		125	3.0
		22.1		130	2.9
6/18/44	9.2			infinity	
	9.6			infinity	
6/20/44	(10)	23.1		120	2.8
		26.1		100	2.6

Date	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	db_T = VII+VIII IX	Observed Visual Range, x_m, Feet XI	x_m/λ_o
6/22/44	10	37	47	85	4.0
		33.6	44	105	4.6
		33.5	43	95	4.1
		30	40	95	3.8
7/22/44	10	34.4	44	78	3.4
		34.2	44	90	4.0
7/25/44	10	49	59	50	3.0
		49	59	50	3.0

TABLE IV

Observations and Results, Observatory Installation,
Data from Recorder Strips

Only such records as indicate stable conditions are used. Decibel calibration recorded just preceding run of 6/15/44, attached to letter of transmittal dated July 3, 1944.

Date	Time	Clear $db_i^o - db_e^o$ VII	Fog $db_e - db_i$ VIII	db_F = VII+VIII IX	Observed Visual Range x_m, Feet XI	x_m/λ_e
5/15/44	9:55A	(10)	25.5	35.5	120	4.3
			23.5	33.5	130	4.3
			27.5	37.5	115	4.3
			31.5	41.5	95	3.9
	10:32A		30	40	90	3.6
			31	41	85	3.5
			32	42	80	3.4
	(1:30P)		44	54	68	3.7
			45	55	75	4.1
5/16/44	1:18P	10.0			infinity	
		10.0			infinity	
6/15/44	10:25A+	(10)	31.5	41.5	80	3.3
			32.5	42.5	78	3.3
			29.5	39.5	100	4.0
7/15/44	12:36P	9.9			infinity	
		9.5			infinity	
		9.4			infinity	
		9.3			infinity	

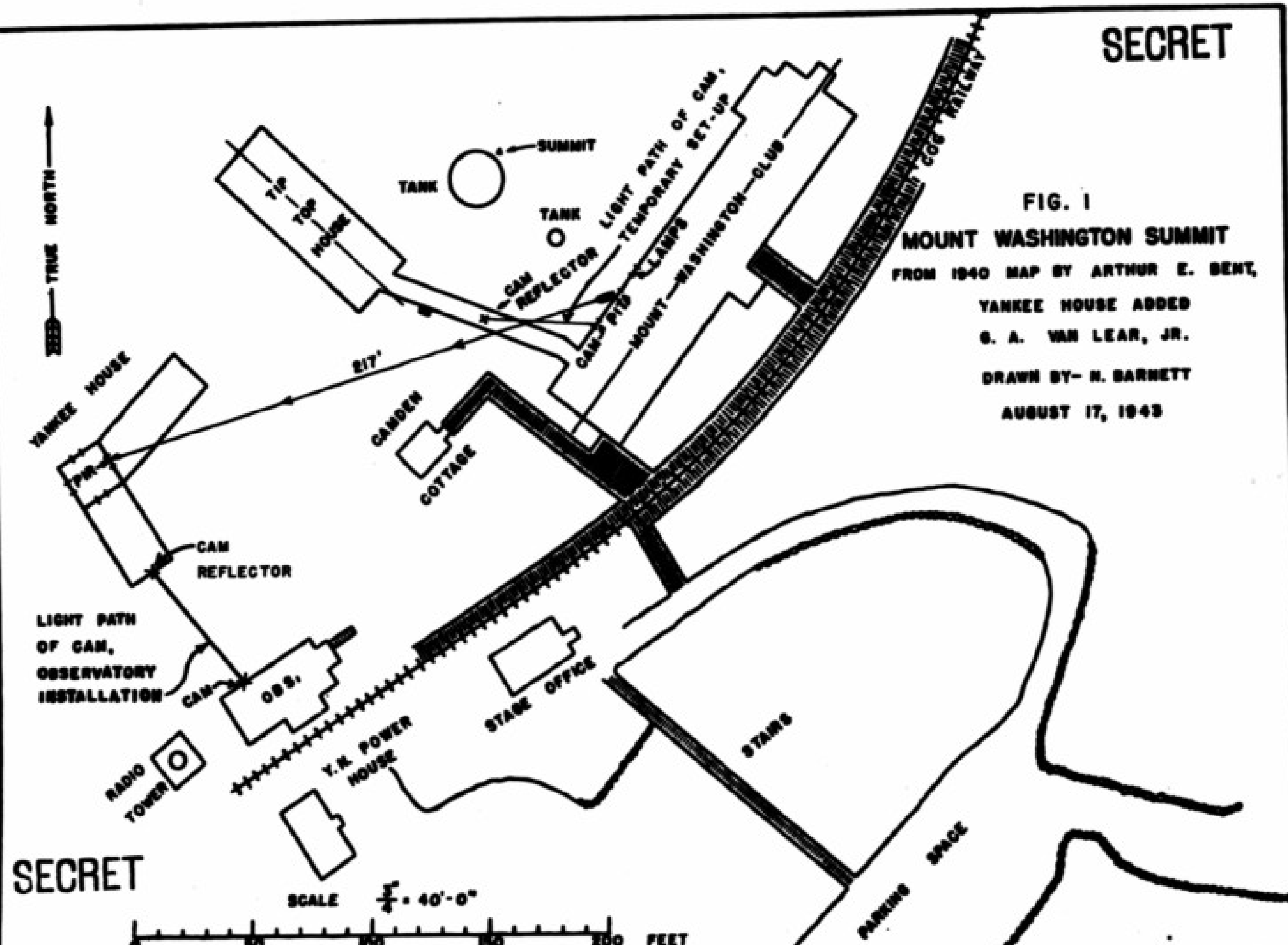
SECRET

FIG. I

MOUNT WASHINGTON SUMMIT

FROM 1940 MAP BY ARTHUR E. BENT,
YANKEE HOUSE ADDED
G. A. VAN LEAR, JR.

DRAWN BY- N. BARNETT
AUGUST 17, 1943



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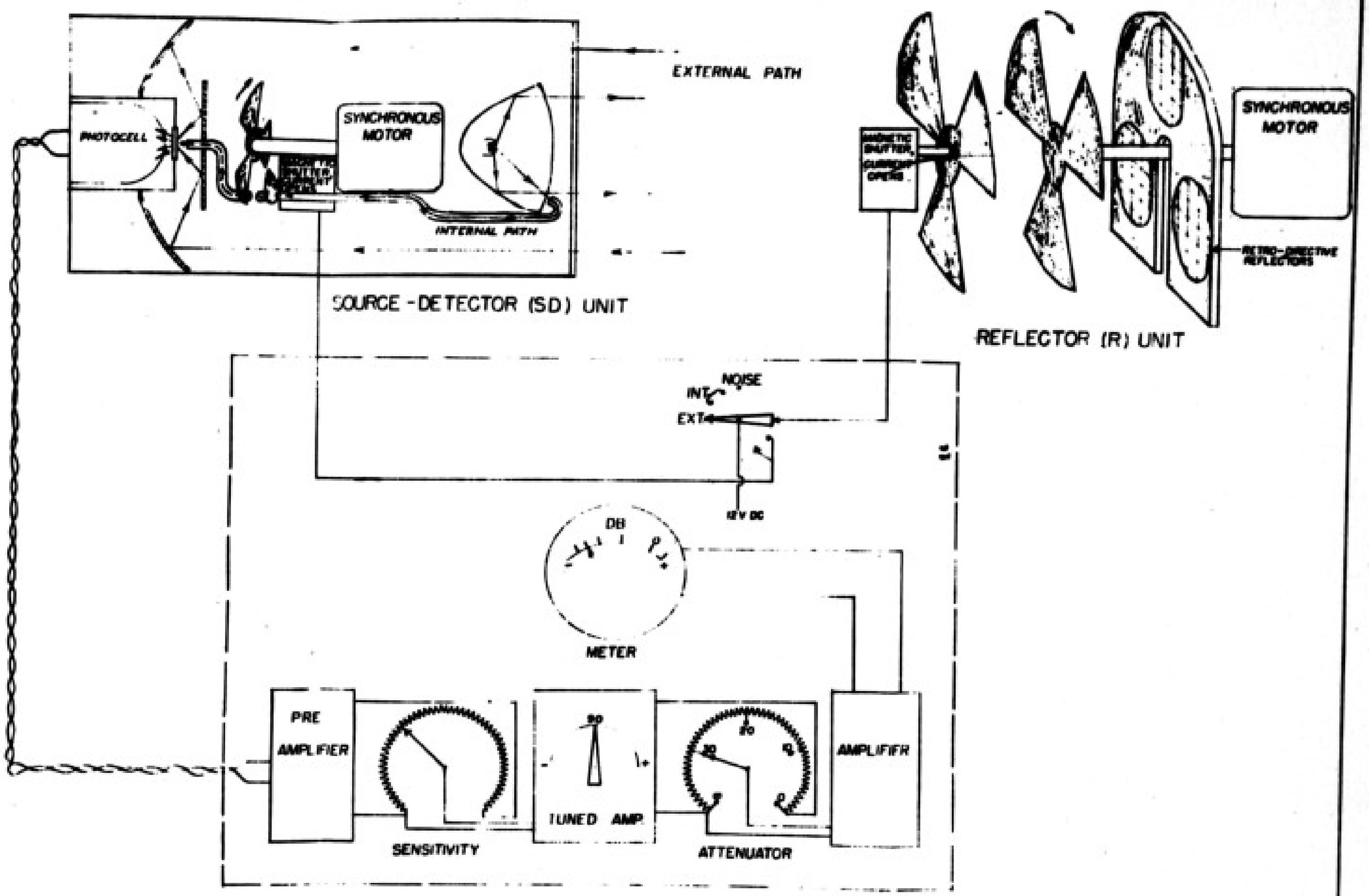

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FIG. 2 SCHEMATIC DIAGRAM OF CLOUD ATTENUATION METER

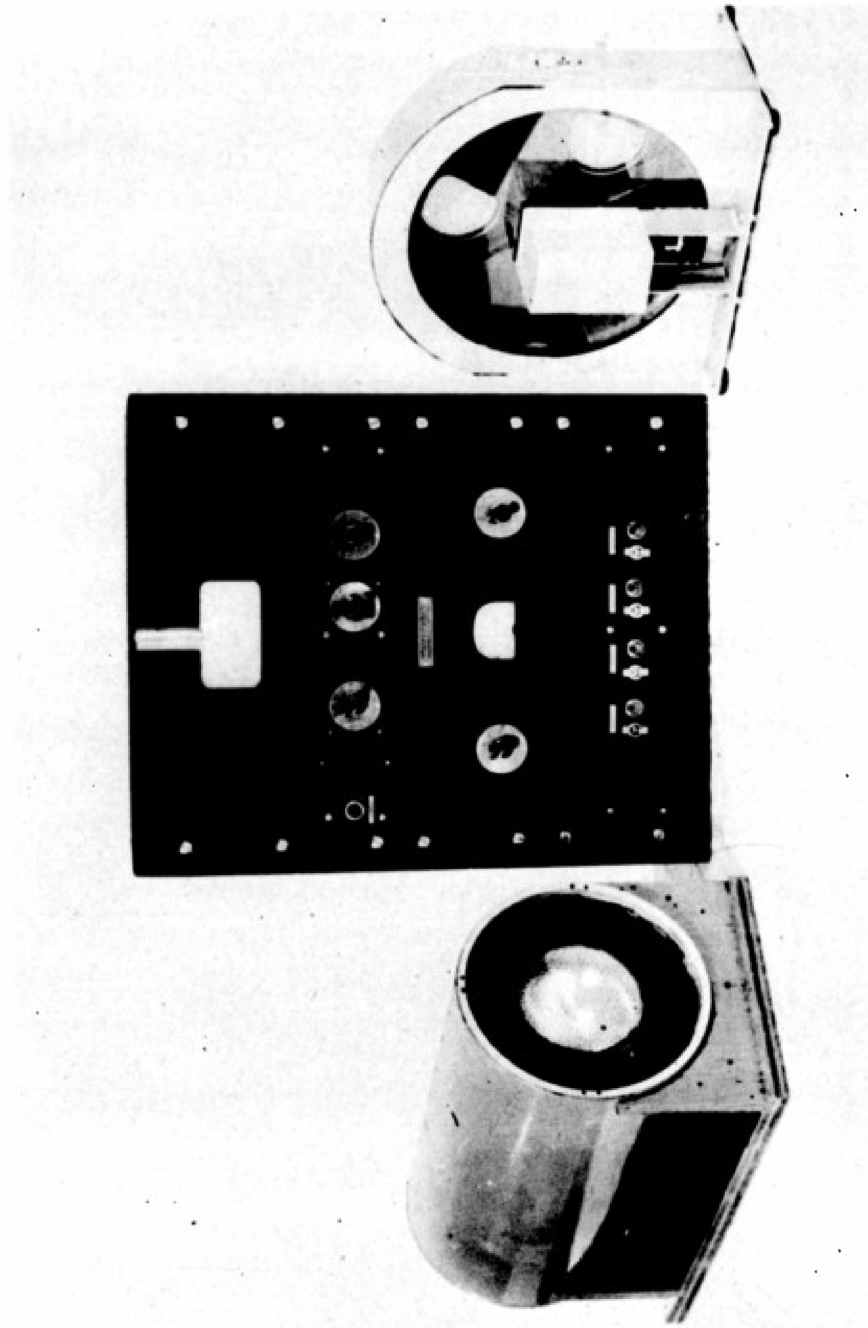


FIGURE 3. CLOUD ATTENUATION METER, GROUP VIEW

SECRET FIG. 4

SECRET FIGURE 4. CONTROL-METER CABINET, INTERIOR

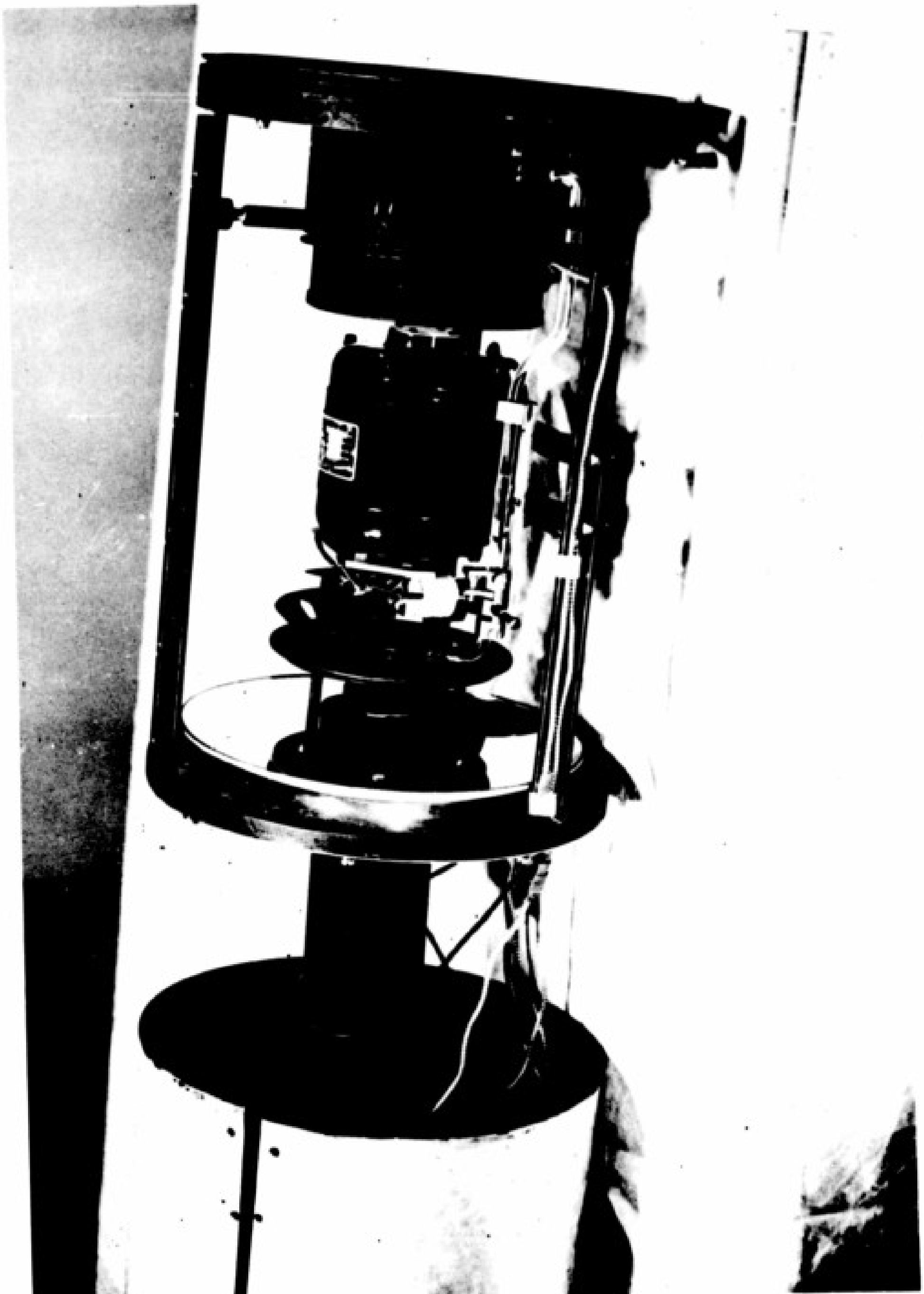
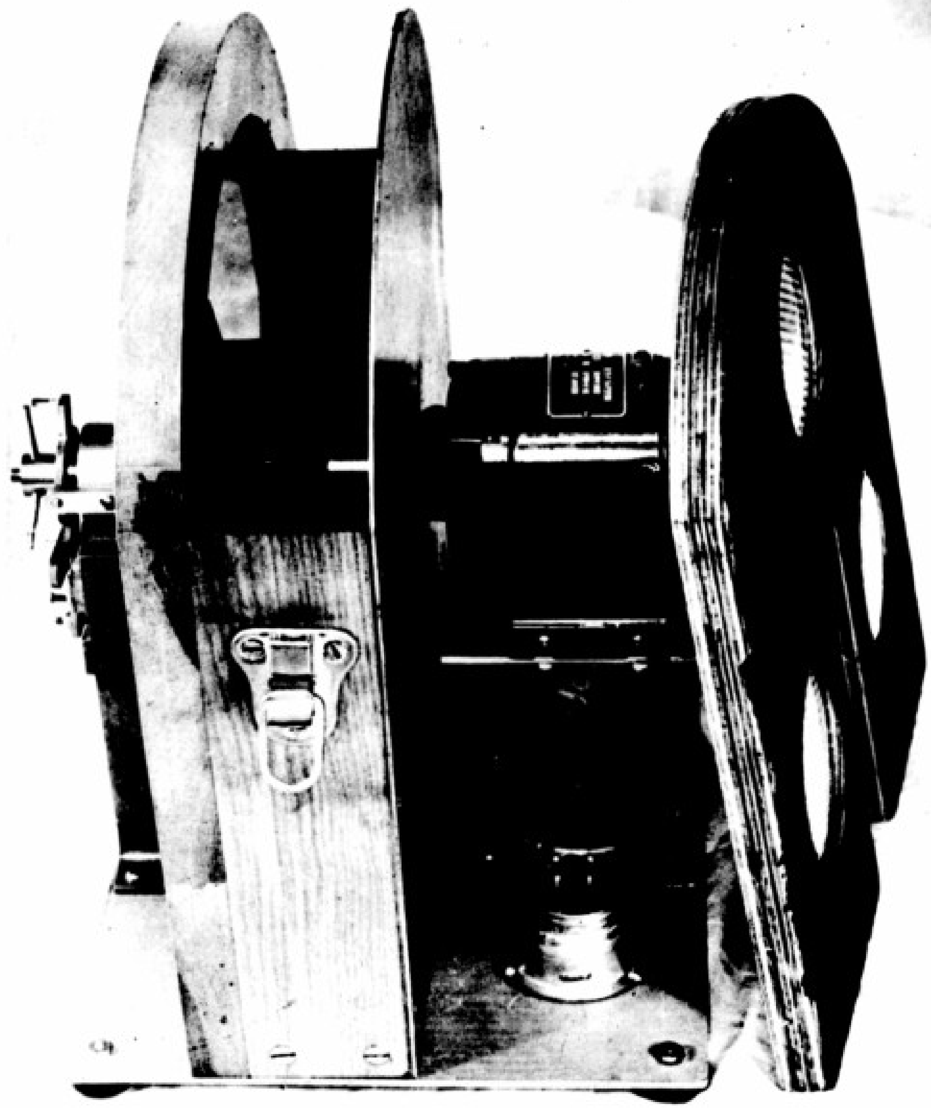


FIGURE 5. SOURCE-DETECTOR UNIT, INTERIOR



SECRET FIGURE 6. REFLECTOR UNIT, INTERIOR

SECRET FIG. 7

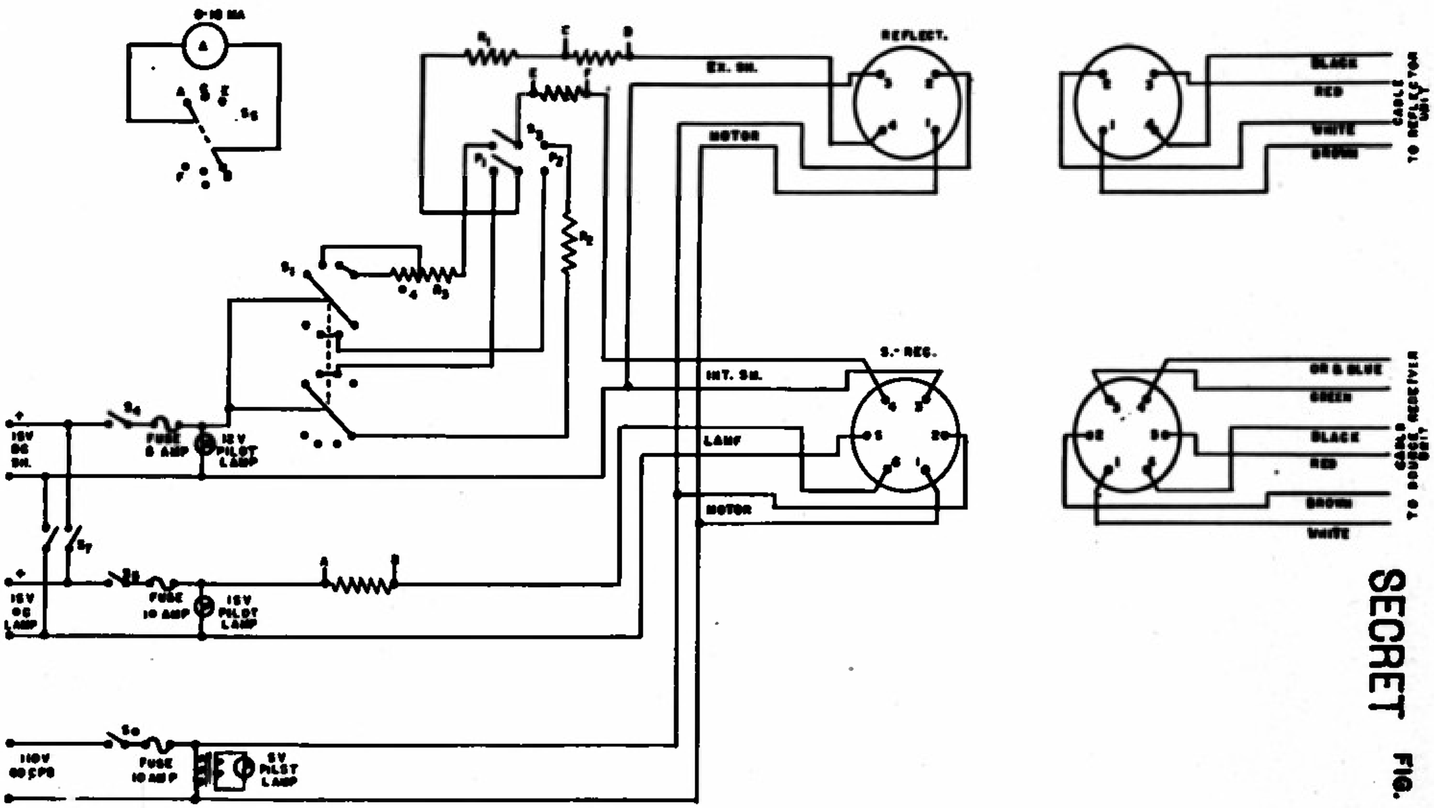


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FIG. 7 DIAGRAMS, CONTROL CIRCUIT

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FIG. 8

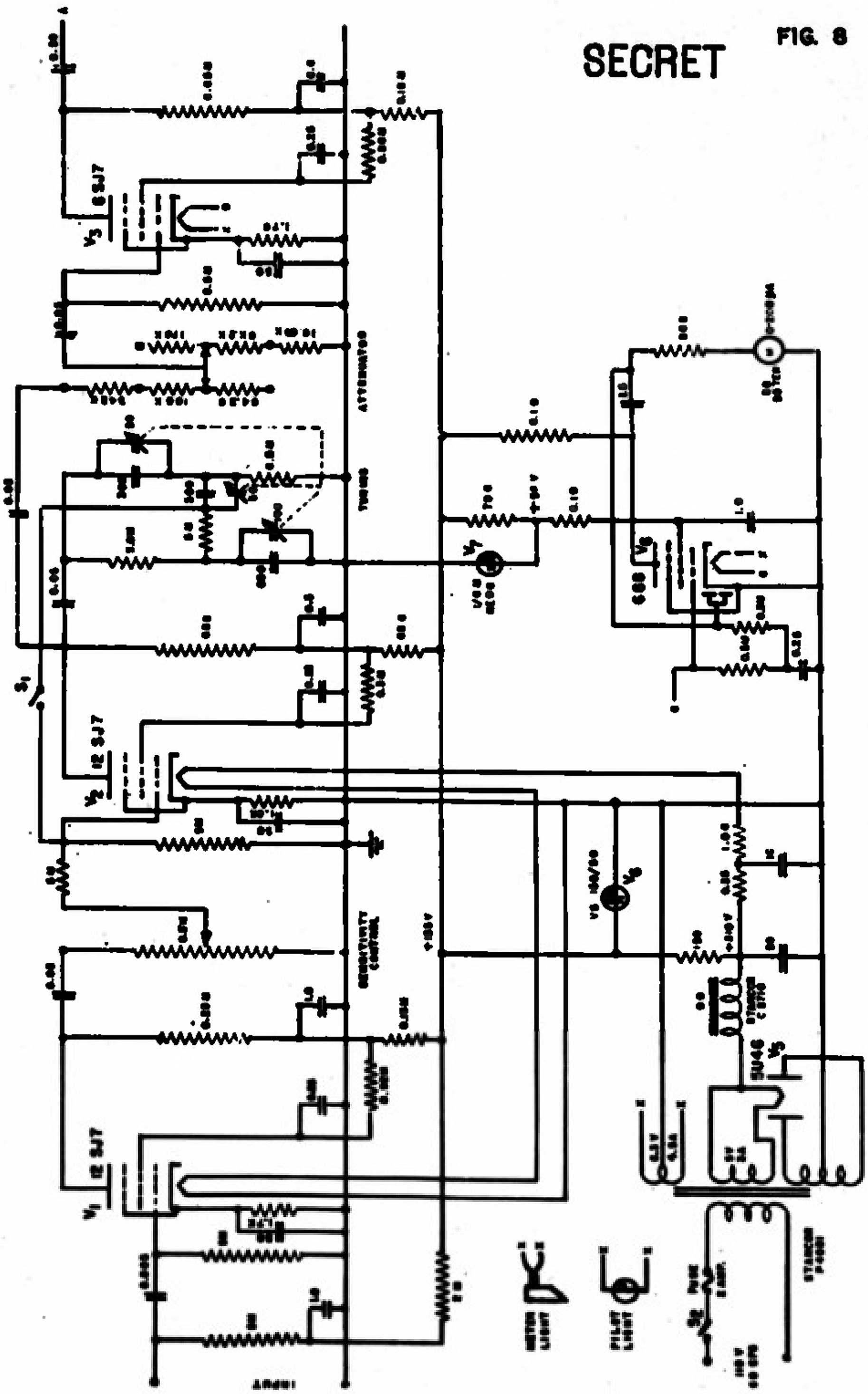

FIG. 8 CIRCUIT DIAGRAM, AMPLIFIER

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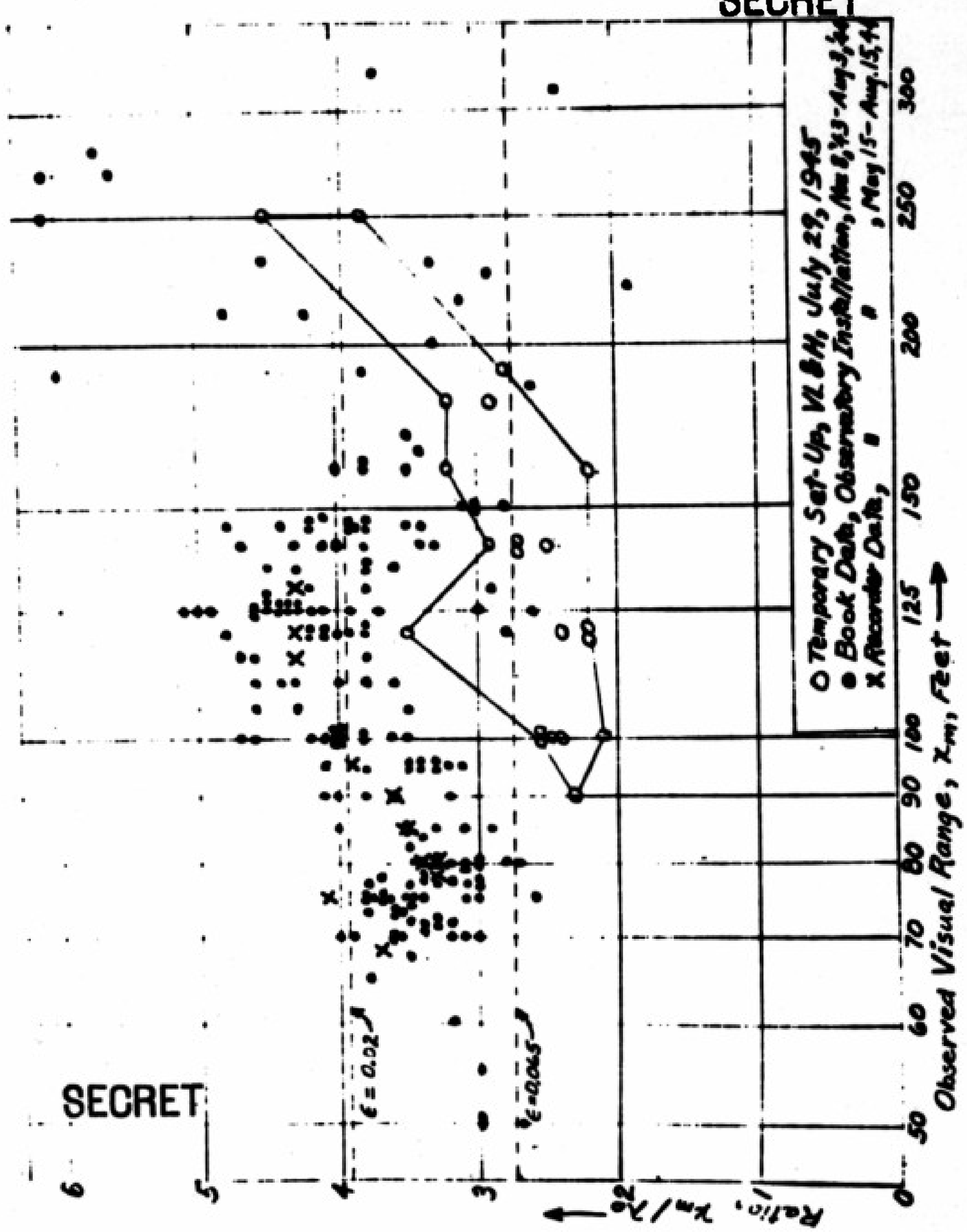

Fig. 9 Data Plot, Ratio x_m/λ_o vs x_m.

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ABSTRACT:

The objective of the work described was to obtain more reliable quantitative information than was available on the attenuation coefficient of clouds and to obtain the correlation between visual range and the attenuation coefficient. A cloud attenuation meter consisting of a source-detector unit, a reflector unit and a control-meter cabinet was used to make simultaneous observations of visual range and optical density. Values found for the coefficient, according to the Lambert-Bouguet law, were between 1.4 and 5.9 per hundred feet.

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